ARLINDO Circulation: The IES Component - Data Analysis and Synthesis

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LONG-TERM GOALS

The Arlindo Project ("Arlindo" is an acronym for Arus Lintas Indonen, meaning 'throughflow' in Bahasa Indonesian) is a joint oceanographic research endeavor of Indonesia and the United States. Arlindo has as its primary goal to study the circulation and water mass stratification within the Indonesian Seas in order to formulate a thorough description of the source, spreading patterns, inter-ocean transport and dominant mixing processes.

OBJECTIVES

The Indonesian Seas are important in terms of both local and larger scale ocean phenomena. The magnitude and variations of the Pacific to Indian Ocean throughflow is considered a key element in the thermohaline balance of the Indian and Pacific Oceans, and perhaps even to the global climate system. Indonesian oceanographic features may influence ENSO by governing the "seepage" of the western tropical Pacific warm pool water into the Indian Ocean. It provides an interactive link between the warm tropical water of these oceans. Furthermore advective and tidal induced mixing may govern to some extent the SST and sea-air coupling, with feedback on ENSO. ARLINDO has as its primary goal to study the circulation and water mass stratification within the Indonesian Seas in order to formulate a thorough description of the source, spreading patterns, inter-ocean transport, and dominant mixing processes. Funds were provided by ONR to the PI (S.L. Garzoli) to complete the PIES field work phase of the project. Four inverted echo sounders equipped with pressure gauges (PIES) were deployed along the main axis of the Makassar strait bracketing the current meter mooring. The objective of these deployments was to measure the meridional throughflow by monitoring the pressure gradient along the strait, and to study internal waves and tides at the Makassar Strait. The choice of the site was based in previous results (Gordon and Fine, 1995) that proved that most of the throughflow from the Pacific to the India Ocean occurs through this strait.

The instruments were deployed during November 1996 and recovered during a cruise that took place in February 1998. Three time series of travel time, three time series of bottom pressure, and temperature were made available for the analysis (one instrument was lost). During the cruises, additional hydrographic data has been collected (CTD, XBT), as well as direct measurements of the currents (ADCP, CMM). The objective of this proposal was to: (1) Perform data reduction, calibration, and analysis. (2) Participate in joint data analysis with other ARLINDO components and PIs. (3) Present the results during national and international meetings and publish them in international journals.

APPROACH

One of the parameters that will be measured with the PIES is the difference of pressure between sites. In a narrow channel in which the effects of rotation can be neglected, all of the flow is in the direction along the channel. The condition for the effects of rotation to be negligible is that the width of the channel is small compared to the Rossby Radius of deformation (R). Due to the proximity to the equator, the Coriolis parameter is almost zero and R is very large. Therefore, it can be assumed that all of the motion will be along the channel. The equations that govern this motion are basically the Bernoulli equation and the mass conservation equation. In first approximation, these equations can be solved for the total velocity, V, and a relation between the difference in pressure and the transport can be obtained. Indeed, all that can measured with a PIES array is the pressure variability (these are free-fall deployed instruments and the depth at which they were deployed is unknown). In order to recall this pressure variability to velocity, all that is needed is a measurement of the current at one point. A current meter mooring was deployed between the PIES and the mean current at the bottom was used as the mean barotropic component. In addition, ADCP haul mounted measurements between the station were obtained to provide another independent variable to calibrate the instruments. The second parameter measured with the IES is travel time, a quantity that is directly proportional to the integrated temperature and that can also be related to dynamic height. This was done suing the hydrographic data collected during the Arlindo cruises.

This work will be completed in collaboration with: Jorina Waworuntu (Graduate Student, RSMAS/UM), Donald Olson (RSMAS/UM) and Amy Ffiled (LDEO/CU). The PIES analysis was part of Jorina's Thesis. Jointly with Donald Olson we prepared a paper on the dynamics of the Makassar Strait. With Amy Ffield, we collaborated on the study of the thermal structure and we will analyze the high frequency oscillations.

WORK COMPLETED

* Reduction and calibration of the 15-month long travel time series collected with the IES.
This was achieved by using the PI's standard programs to transform the number of counts from the 24 returns into travel time. After that the series were de-picked, eventual missing points interpolated, and the travel time series became ready for scaling to physical parameters: depth of the main thermocline, dynamic height and integrated temperature.

* Reduction and calibration of the 15-month long series collected with the pressure sensors.
The first step was to transform the number of counts into pressure. To do that the formulas and calibration constants provided by the manufacturers were used. Bottom-deployed pressure sensors provided a measurement of the variability in pressure. Using the ADCP data and the current meter series, the variability in pressure can be scaled to velocity (Garzoli *et al.,* 1996).

* Analysis of the data
The data was analyzed to study the transport across the Makassar Strait. The data was also made available to other Arlindo PIs for their usage in combinations with other data sets.

* Moeling of the Makassar Strait transport
The first model developed was based on the Bernoulli equation and conservation of mass. This was done on the assumption that in a narrow channel, in which the effects of rotation are neglected, the mean flow is directed in the direction along the channel. Results from this model indicated that the

dynamics of the Makassar Strait involves dynamics more complicated than a two-layer model. A simple three layer model was developed using as parameters to solve the equations the pressure and depth of the upper layer derived from the PIES and data from TOPEX/POSEIDON for the sea surface height.

RESULTS

The following papers were submitted for publication:

"Dynamics of the Makassar Strait" (J. M. Waworuntu, S. L. Garzoli and D. B. Olson) Submitted to GRL, July 1999.

One of the key results derived from this study is that the flow in the Makassar Strait is not purely barotropic and therefore can not be obtained as a difference in bottom pressure. The structure of the baroclinic component demands the use of a minimum of three layers to model the flow. A three-layer model was solved using the PIES data and TOPEX/POSEIDON data. The model solutions for the three-layer system show some interesting results. 1. The top interface shoals (the top thickens decreases) during 1997. This is consistent with the strong El Niño onset in 1997, when the warm pool in the western equatorial Pacific moves eastward, causing the thermocline to shoals in the Indonesian Seas. 2. The middle layer stretches in the opposite phase as compared with a top layer. The middle layer thickens most of the 1997 year. 3. The bottom layer present slight changes during the measurement period. 4. A warm event is observed first in the Labani constriction around December 1996 and later to the north in January 1997. The velocities and variability in the upper layer are much larger that in the lower layers. Comparison between the model transport and the transport measured by the current meter mooring indicate that even when both curves follow a similar trend, the variability in the model transport is much larger. This can be attributed to the fact that the CMM transport is extrapolated from 200 m up due to the lost of the upper current meter. Observations of the upper and middle layers is necessary to monitor the troughflow in the Makassar Strait.

"Temperature variability within the Makassar Starit (A. Ffield, K. Vranes, A. L. Gordon, R. D. Susanto and S. L. Garzoli) Submitted to GRL, July 1999.

The analysis of a subset of the Arlindo observations of ocean temperatures and PIES data, provide the first high resolution, long term record of of temperature variability in the Makassar Strait of the Indonesian Seas. The mooring observations span the entire cycle of the strong 1997/1998 El Niño. A high correlation is found between variability in the average thermocline temperature, to variability in the southward Makassar volume transport: during the high (low) volume transport, the average temperature of the thermocline is also high (low). In addition during the measurement period, the Makassar thermocline temperature is highly correlated to NINO3. This reveals that the Makassar temperature field- when coupled with the troughflow – transmits the equatorial Pacific El Niño and La Niña temperature fluctuations into the Indian Ocean. In 1997 the internal energy transport was 0.5 PW, lower than the model estimates; during La Niña the internal energy transport is expected to be several PW higher.

IMPACT/APPLICATIONS

The moorings deployed during Arlindo (PIES and current meters) were the first ones to be deployed in Indonesian waters. The data collected provided the first time series of the through flow across the Makassar strait, the major conduit for the exchange between the Pacific and Indian Oceans. This is a critical parameter to understand inter-ocean exchange. Inter-ocean transport within the Indonesian Seas is the primary means of exporting excess fresh water from the North Pacific Ocean. The efficiency of this transfer dictates to a large measure the meridional overturning of the Pacific and Indian Oceans and perhaps of the global thermohaline "conveyor belt." These processes are relevant to climate issues. In particular, to the El Niño phenomena as it allows a transfer of warm water in the eastern Pacific into the Indian Ocean, adjusting the volume of the warm pool.

TRANSITIONS

As it was explained before, measuring the throughflow is of critical importance for the understanding of oceanic circulation and climate. Results from the analysis done during the course of this grant will be used to determine the optimal (cost/efficient) minimum array necessary to monitor the throughflow.

RELATED PROJECTS

This program is a component of the NSF and ONR funded Arlindo Circulation Program (Arnold Gordon, US Chief scientist). Components of Arlindo Circulation are: Current meter moorings (D. Pillsbury, PI) and Temperature pods (A. Ffield and S.L. Garzoli, co-PIs); PIES (S. L. Garzoli, PI); CTD oceanographic stations (A.L. Gordon, PI), and tracers (R. Fine, PI); shallow Pressure Gauges (N. Bray, PI); large scale remote sensing (C. Koblinski).

REFERENCES

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